Guide to Nonlinear Modeling Parameters for Earthquake-Resistant Structures

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This guide provides information regarding nonlinear modeling of components in special moment frame and structural wall systems resisting earthquake loads. The reported modeling parameters provide a modeling option for licensed design professionals (LDPs) performing nonlinear analysis for performance-based seismic design of reinforced concrete building structures designed and detailed in accordance with ACI 318.

Keywords: backbone curve; beams; columns; coupling beams; earthquake-resistant structures; flexure; joints; modeling parameters; nonlinear analysis; performance-based engineering; seismic design; shear; special concrete moment frames; special concrete shear walls; special structural walls.

CONTENTS

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

This guide provides nonlinear modeling parameters that will assist the licensed design professional (LDP) in the use of performance-based seismic design of new concrete buildings. Performance objectives are assigned for the given structure and compliance with the performance objectives are then evaluated based on the deformation of structural elements rather than evaluated based on strength under prescriptive requirements. Deformations in structural components allow the LDP to understand damage levels related to seismic hazards.

There are currently several documents that provide general analysis procedures for the design of new buildings using performance-based engineering (ASCE/SEI 7; Structural Engineers Association of Northern California [SEAONC] 2008; Los Angeles Tall Buildings Structural Design Council [LATBSDC] 2014; Pacific Earthquake Engineering Research Center [PEER] [PEER/ATC 2010]). Although these documents provide a means for seismic design indicative of earthquake hazards and acceptance criteria that are similar to ASCE/SEI 41, they do not provide the required information for modeling nonlinear behavior of a structural component based on detailing conditions, such as the development of force-deformation backbone curves shown in Fig. 1.1. This guide provides modeling parameters that can be used to generate the backbone curves of structural members of special moment frame and structural wall systems detailed per Chapter 18 of ACI 318-14.

For example, an engineer modeling the nonlinear deformation of a structural wall with specific reinforcement configurations for new design can select from the following three alternatives: 1) develop modeling parameters from existing experimental data; 2) develop and implement a new testing program; or 3) create force-deformation curves using the information in the existing building standard (ASCE/SEI 41) or guideline (ACI 369R) developed for seismic evaluation and rehabilitation. The existing experimental data, however, are not always available, and new testing programs may be limited by budget and project schedule. In addition, the modeling parameters in the existing building standard do not always adequately represent the behavior of components designed according to current codes. Furthermore, they may not be directly applied to new design due to incongruences in parameter definition and requirements across documents. This guide provides a set of nonlinear modeling parameters that can be used without performing one of the three alternatives given.

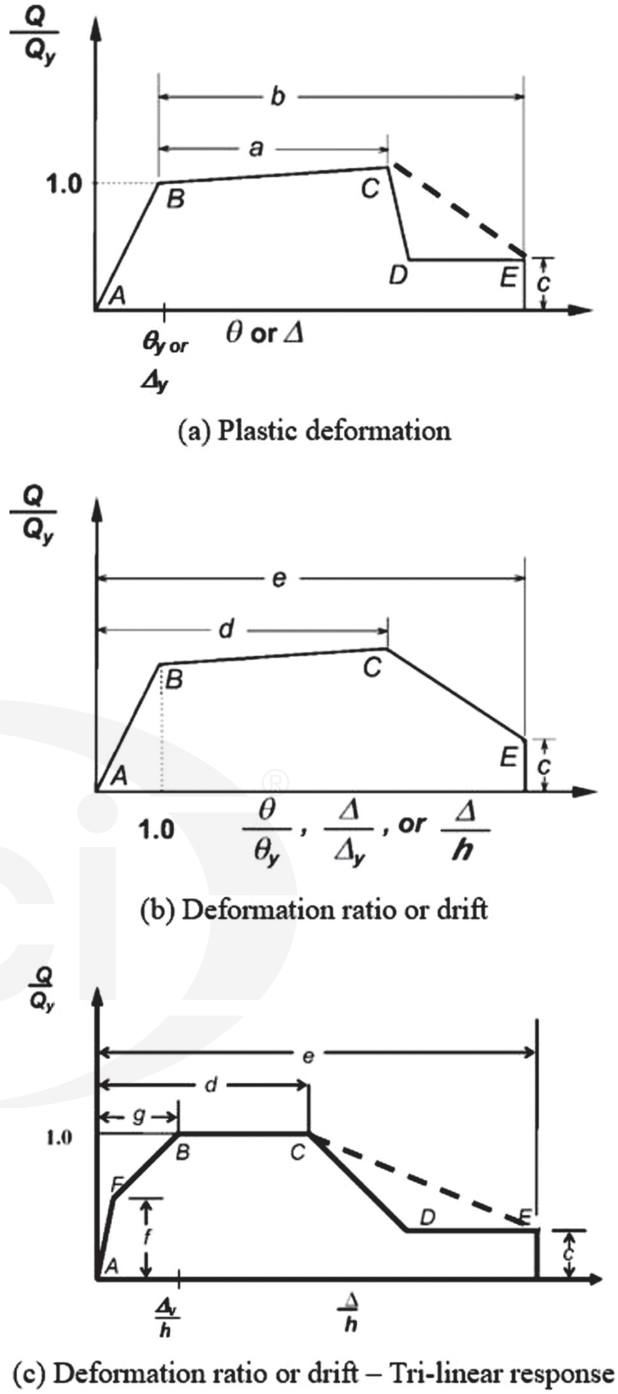

Fig. 1.1—Generalized force-deformation relations for structural concrete components (ASCE/SEI 41). (Note: a, b, d, e, f, *and* g *are deformations as defined in the reported nonlinear modeling parameter tables.)*

1.2—Scope

This guide provides information about nonlinear modeling parameters for:

(a) Special moment frames extracted from ASCE/SEI 41, for which definitions and requirements are converted to those of the codes for the design of new concrete buildings

(b) Special structural walls and coupling beams extracted from ASCE/SEI 41, for which definitions and requirements are converted to those of the codes for the design of new concrete buildings

(c) Special moment frames and structural walls developed from the latest experimental databases of structural components compliant with the requirements of Chapter 18 (ACI 318-14) for earthquake-resistant structures.

In regards to (c), the mean and mean minus one standard deviation modeling parameter values are provided for these code-compliant specimen databases in an effort to demonstrate a quantitative representation of data distribution for the LDP. The LDP can select modeling parameters based on ASCE/SEI 41, or the experimental database, depending on project constraints, jurisdiction requirements, or both.

The modeling parameters in this guide are meant to be used for the analytical modeling of structural components in earthquake-resistant systems as described. The guide, however, does not describe global behavior or provide interaction between different systems in the buildings, for example, diaphragms and moment frames.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_{cv} = gross area of concrete section bound by web thickness and length of section in the direction of shear force considered, in.^{2} (mm^2)

A_g = gross area of concrete section, in.^{2} (mm^2)

A_j = effective cross-sectional area within a joint in a plane parallel to plane of beam reinforcement generating shear in the joint, in.^{2} (mm^2) (ACI 318-14 Section 18.8.4.3)

A_s = area of nonprestressed longitudinal tension reinforcement, in.^{2} (mm^2)

A_s' = area of compression reinforcement, in.^{2} (mm^2)

A_v = area of shear reinforcement within spacing s, in.^{2} (mm^2)

b = width of compression face of member, in. (mm)

b_w = web width, or diameters of circular section, in. (mm)

d = distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in. (mm)

E = effect of horizontal and vertical earthquake-induced forces

E_c = modulus of elasticity of concrete, psi (MPa)

E_s = modulus of elasticity of reinforcement and structural steel, psi (MPa)

f_c' = specified compressive strength of concrete, psi (MPa, $\sqrt{f_c'}$ in MPa = $12\sqrt{f_c'}$ in psi)

f_y = specified yield strength of reinforcement, psi (MPa)

h = height of member along which deformations are measured, in. (mm)

h_b = subgrade dimension from absolute base of wall to grade level, in. (mm)

h_c = average height of the beams framing into the joint in the direction of applied shear, in. (mm)

h_{eff} = effective shear span of wall, in. (mm)

h_w = height of entire wall from base to top, or clear height of wall segment or wall pier, in. (mm)

I_{cr} = moment of inertia of cracked section transformed to concrete, in.^{4} (mm^4)

I_g = moment of inertia of gross concrete section about centroidal axis, neglecting reinforcement, in.^{4} (mm^4)

L = length of member along which deformations are assumed to occur, in. (mm)

ℓ_d = development length in tension of deformed bar, deformed wire, or plain wire reinforcement, in. (mm)

l_p = assumed plastic hinge length, minimum of the following: $0.5l_w$, the first-story height, and $0.5h_w$ for wall segments, in. (mm)

l_w = length of entire wall, or length of wall segment or wall pier considered in direction of shear force, in. (mm)

M_n = nominal flexural strength at section, in.-lb (N-mm)

M_{pr} = probable flexural strength of members, with or without axial load, determined using the properties of the member at the joint faces assuming a tensile stress in the longitudinal bars of at least $1.25f_y$ and a strength reduction factor ϕ of 1.0, in.-lb (N-mm)

P = design axial force obtained from design load combinations that include overstrength factor or determined from limit-state analysis, lb (N)

Q = generalized force demand in a component

Q_y = yield strength of a component

s = center-to-center spacing of transverse reinforcement, in. (mm)

V = design shear force obtained from design load combinations that include overstrength factor or determined from limit-state analysis, lb (N)

V_e = design shear force for load combinations including earthquake effects, lb (N) (refer to ACI 318-14 Sections 18.6.5.1 and 18.7.6.1.1)

V_n = nominal shear strength, lb (N)

V_o = shear strength of a column per ASCE/SEI 41 Eq. (10-3), lb (N)

V_p = shear demand on a column at flexural yielding of plastic hinges per ASCE/SEI 41 Section 10.4.2.2.2, lb (N)

V_{si} = nominal shear strength provided by shear reinforcement, lb (N)

Δ = generalized deformation, in. (mm)

Δ_y = generalized yield deformation, in. (mm)

ε_y = yield strain of reinforcement, in./in. (mm/mm)

θ = generalized deformation, radians

θ_y = generalized yield deformation, radians

ϕ = strength reduction factor

ϕ_y = yield curvature at section, 1/in. (1/mm)

ρ = ratio of nonprestressed tension reinforcement

ρ' = ratio of nonprestressed compression reinforcement

ρ_b = ratio of A_s to bd producing balanced strain condition

ρ_v = ratio of A_v to b_ws